



Stochastic Source Inversion Methodology and Optimal Sensor Network Design

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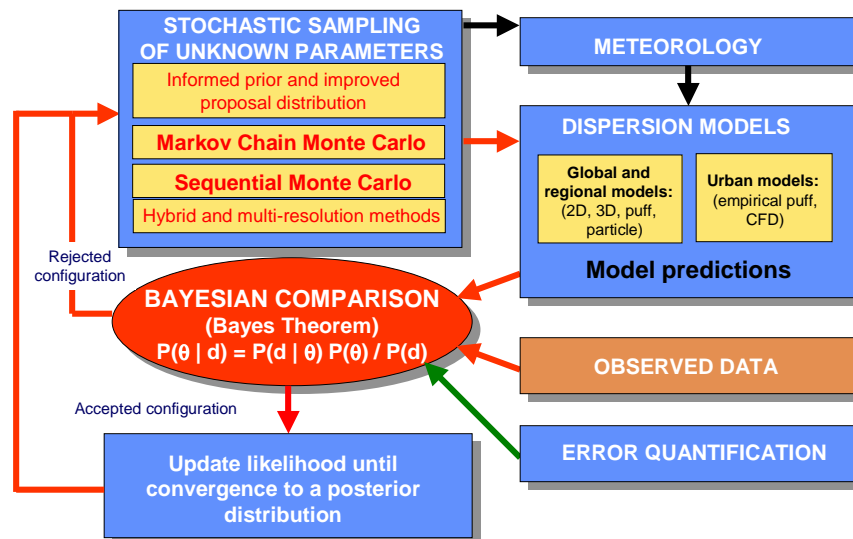
Event Reconstruction Answers the Critical Questions: What? When? Where? How Much?



- n Atmospheric releases are one of the most highly effective and rapid means to impact large populations
- n Primary uncertainty due to unknown sources and meteorology
- n Our approach couples data and predictive models to provide
 - Backwards analyses to determine unknown source characteristics
 - Optimal forward predictions for consequence assessment
 - Dynamic reduction in uncertainty as additional data become available



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- Figure 1 consists of two panels. The left panel is a map titled 'Measurement Locations' showing the location of Ispra, Italy, with a scale bar from 0 to 1000 km. The right panel is a line graph titled 'Ispra, Italy' showing the '24-hr average PM_{10} concentration ($\mu\text{g}/\text{m}^3$)' on the y-axis (0 to 1250) against 'Measurement Ending Date' on the x-axis (20 June 2016 to 20 June 2017). The graph compares 'Measured' data (red line with circles) and 'IS7.5' model results (blue line). The measured data shows a sharp peak of approximately 900 $\mu\text{g}/\text{m}^3$ in late 2016, while the IS7.5 model shows a peak of approximately 750 $\mu\text{g}/\text{m}^3$ in early 2017. A yellow box highlights the period from June 2016 to June 2017.

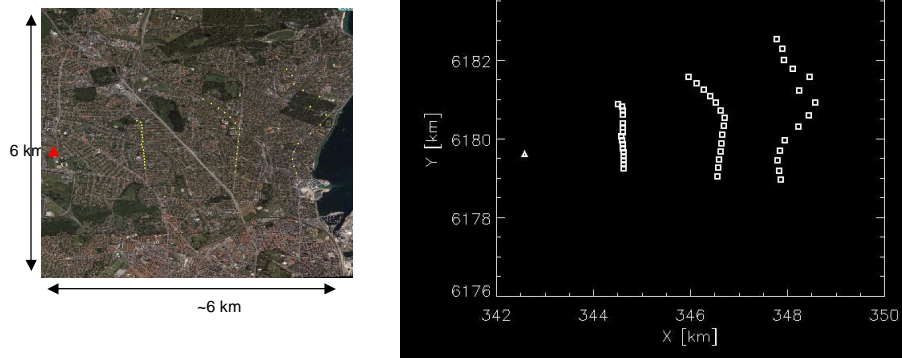
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Copenhagen Tracer Experiment is Used to Demonstrate MCMC Event Reconstruction



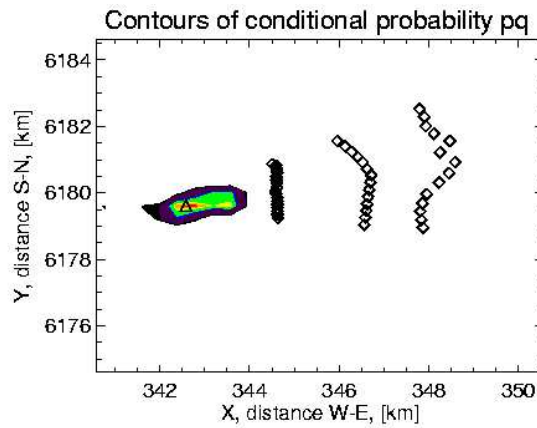
SF6 gas was released at a constant flow rate from a TV tower (115m high). The dispersal of this passive tracer over residential Copenhagen was observed using three arcs of sensors located near the surface at ~ 2, 4, and 6 km from the source. Each of the ~ 50 sensors provided 3 samples (20-minute averages) of atmospheric concentrations of SF6 during the dispersion experiment.

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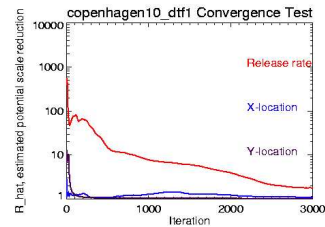
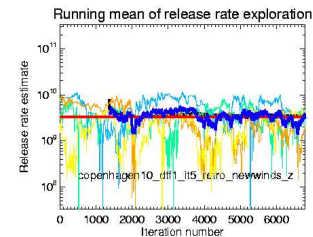


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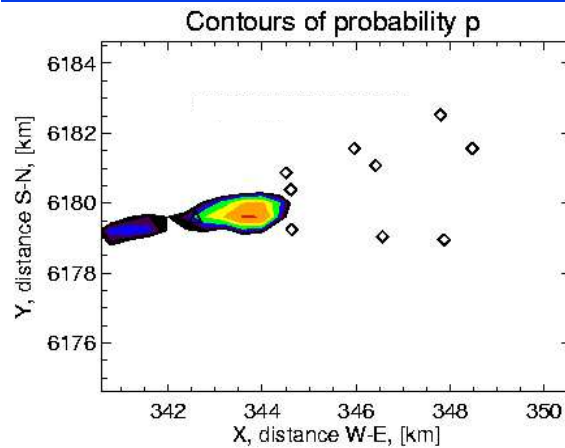


The “answer” consists of a probability distribution of possible source locations, with the most likely locations weighed most heavily (here in warm colors). Contours represent probability mass in 10% increments; yellow includes cells which account for top 30% of probability mass; blue = 50%.



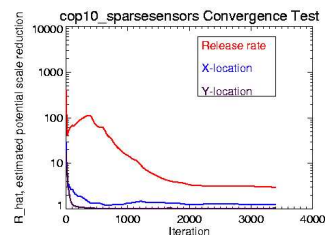
Convergence ($R_{\text{hat}} \rightarrow 1$) attained very quickly for source location.

Using a Reduced Number of Sensors, Source Location Can Still Be Estimated

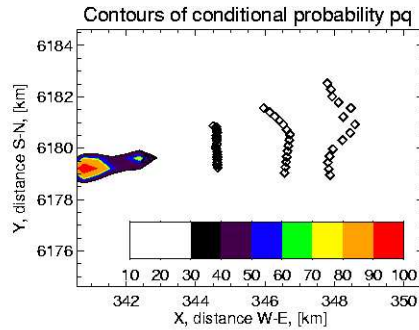


The confidence region is larger in this case and the actual source falls in the top 50% of probability mass.

Note the probability distribution is broader compared to that of the inversion with all sensors.

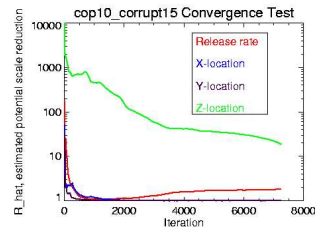
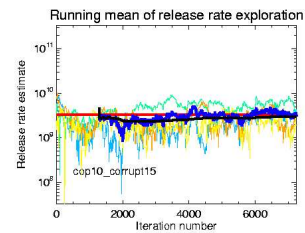


IOP10: Even With “Broken” Sensors We Can Identify Source Location



15 sensors in the domain were “broken”:

	Interval 1	Interval 2	Interval 3
False alarm	7	8	3
False “zero”	6	6	5
Stuck at wrong nonzero	2	1	6

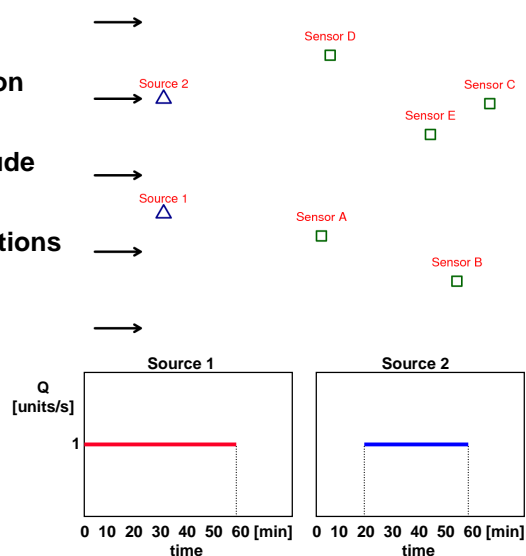


Although convergence is achieved quickly, the performance degrades. Estimates of source release rate are also slightly less accurate.

Stochastic Methodology Is Used To Reconstruct Events With Multiple Sources



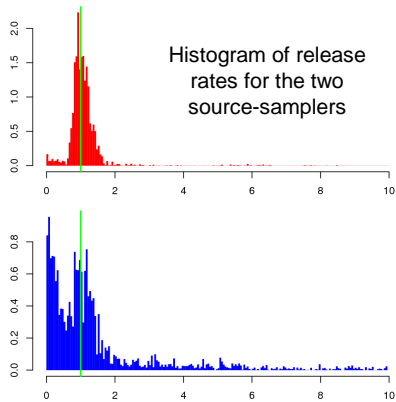
- n Synthetic data generated for five sensors from two stationary sources using INPUFF Gaussian dispersion model
- n Synthetic sensor data include realistic error
- n Uniform (flat) prior distributions assumed for:
 - time of initial release
 - two source locations
 - source release rates



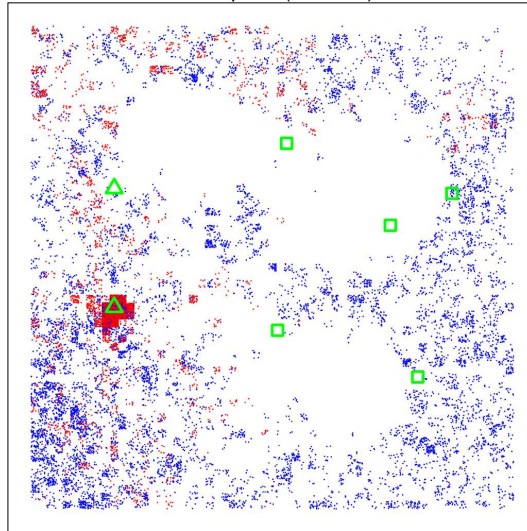
Posterior Inference at $t = 2$



- After two 10min time periods: source 1 has been active for two periods, but source 2 is not active



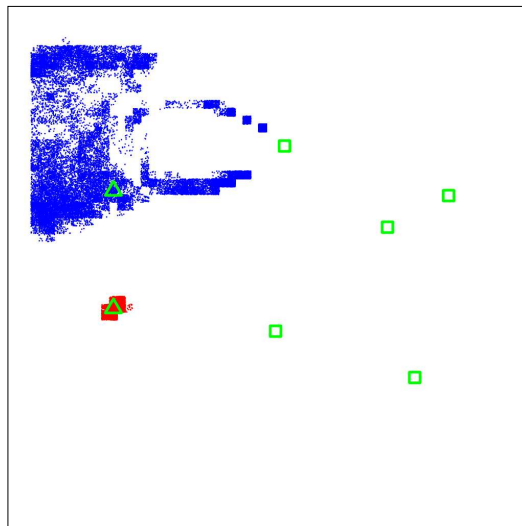
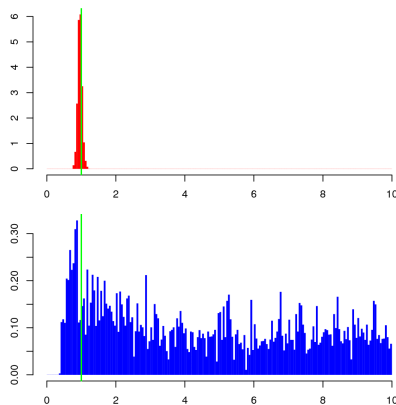
source location realizations sampled by the two samplers (red/blue)



Posterior Inference at $t = 4$



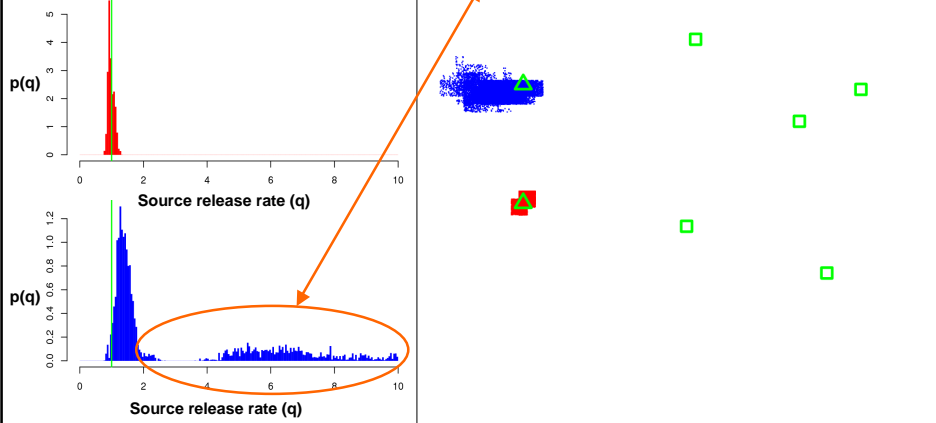
- After four 10min time periods. Source 1 has been active for four periods, but source 2 for two periods



Multiple possible sources are identified using six ten-minute average concentrations



n After six 10min time periods; source 1 has been active for six periods, source 2 active for four periods



Optimization Is Used to Design A More Effective Sensor Network



The goal is to design a sensor network which enhances our ability to reduce uncertainty in a reconstruction of a potential release event

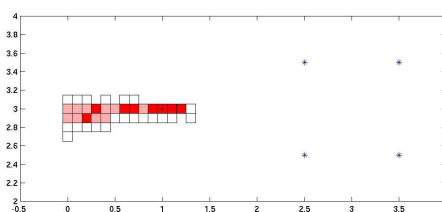
Approach

- \$ Minimizes some measure of the covariance matrix of source parameters for a set of possible releases
- \$ Derivative-free optimization
- \$ Sensitivity-based approximation of the covariance matrix of sensor measurements

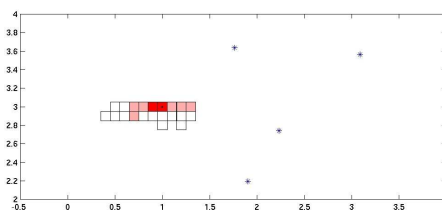
Example

- \$ Scenario consists of 8 possible releases of unit strength
- \$ Multiple initial guesses using Latin Hypercube Refinement
- \$ Sensitivities using finite-differences (for source location) and Green functions (for source strength)
- \$ Reconstruction using the optimized sensor network is more accurate (see 50%, 90%, and 100% confidence sets for source location)

MCMC results for square sensor network



MCMC results for optimized sensor network



Computational Framework Will Support Multiple Stochastic Algorithms, Models, and Platforms

